MSP-82-04

Evaluation of Galvanized Rebars for Concrete Bridge Decks

– Interim Report –

H.J. Fromm
Senior Research Officer

F. Pianca
Research Engineer

Published by:
The Research and Development Branch
Ontario Ministry of Transportation and Communications
Hon. James W. Snow, Minister
H.F. Gilbert, Deputy Minister

Published without prejudice
as to the application of the findings.
Crown copyright reserved; however, this
document may be reproduced for non-commercial
purposes with attribution to the Ministry.

For additional copies write:
The Editor
Research and Development Branch
Ministry of Transportation and Communications
1201 Wilson Avenue
Downsview, Ontario
M3M 1J8

October 1982

INTRODUCTION

The durability of concrete bridge decks has been recognized as a serious problem for a number of years (1, 2, 3, 4, 5). The problem is mainly due to the corrosion of the reinforcing steel (rebars). This corrosion causes surface spalls and delaminations within the bridge decks. The bridge steel is normally passive in new concrete where the pH is around 12.5. When, however, deicing salt brines permeate the concrete, corrosion is initiated and the buildup of corrosion products on the rebars exerts pressure on the concrete, causing spalls and delaminations (6). This problem is heightened when the concrete cover over the rebars is less than 50 mm, thus permitting more rapid entrance of the brine solution (7, 8). This is a very serious problem with existing bridges, and it is costing huge sums of money for repairs. This problem will continue to be present as long as the existing bridges are still in use.

It was obvious that something had to be done for new bridges to alleviate this problem. Coated steels and greater depths of cover are now being specified by many agencies. In 1962, Lewis tested epoxy coated steel (9) and found it superior to bare or galvanized steel in corrosion resistance, and it did not impair the bond.

In 1974, Pike, Hay, et al (10), published a paper dealing with nonmetallic coatings and showed that electrodeposited epoxy powder provided a corrosion resistant coating for bridge deck rebars. These coatings were further tested by Clear (11), whose work showed that small, bared areas of steel due to scratches, should not present a corrosion problem. As a result of these and other investigations, this Ministry adopted a specification in 1980, which called for epoxy coated rebars in bridge decks. This specification demands an absolute minimum cover of 50 mm over the top steel and requires all steel within 100 mm of the top surface of the deck to be epoxy coated. The ACI also has recommended fusion bonded epoxy coatings for rebars in the ACI 345 Standard Practice for Highway Bridge Deck Construction.

In addition to the research which has been done on nonmetallic coatings, metallic coatings have also been widely investigated. This work includes copper, nickel and zinc coatings, and has been reported by Baker, et al (12). Zinc coatings,

or galvanizing, have been used for years to protect exposed steel surfaces from the elements. Zinc has also been used in an attempt to protect rebars from corrosion. There are many reports in the literature dealing with the performance of galvanized rebars. The reports on work in North America are generally favourable to zinc, and claim that it affords protection to the steel. The reports coming from Europe are, however, generally not in favour of galvanizing.

Stark and Perenchio, in America (13), have issued a report on the performance of eight bridge decks in Bermuda, Canada, and the USA, and on a series of elevated slabs, and they find the performance of galvanized steel very satisfactory and superior to the performance of uncoated steel. Work by Cornet and Bresler (14) and by Cornet, Ishikawa and Bresler (15), indicate that galvanizing should provide increased resistance to corrosion of steel in concrete.

On the other hand, however, the European experience is not so favourable. In a brief paper, Arup (16), lists several instances of failure of galvanized bars in concrete, and says that more experience with this product is necessary before a decision can be made. Unz (17), found that galvanized steel passivates at low chloride contents, but at high chloride contents, inherent currents develop and severe pitting can result in previously passivated galvanized coatings. In America, Stratfull (18), found that some laboratory specimens of galvanized rebars in concrete cracked after only six months' exposure to salt solutions.

The results obtained by Stratfull (18), caused considerable controversy, as shown by the discussion at the end of his paper. Since a few bridges using galvanized rebars had been built in Ontario by some municipalities, it was decided to investigate further, the use of galvanized steel and test some of the bridges which had been constructed.

EXPERIMENTAL

Laboratory Samples

A series of concrete test samples were made up for immersion in a salt solution. There were three series of samples using: a) Black iron rebars; b) galvanized (hot dipped) rebars and, c) chromate treated galvanized rebars. Three strengths of concrete were used for each series: 17.2 MPa, 27.6 MPa, and 34.5 MPa (2,500, 4,000, and 5,000 psi), and three depths of cover in each series and concrete strength were used: 18 mm, 38 mm, and 63 mm. The rebars used, were all No. 6 bars. The samples were poured in wood forms to produce a sample 150 mm wide by 300 mm high, with three thicknesses, depending on the depth of cover. The cement used was a Type 10, meeting CSA-A5.

The formulae for the three mixes were as follows:

Mix	17.2 MPa	27.6 MPa	34.5 MPa
Cement, kg	25.4	32.4	40.7
Fine Agg., kg	96.8	88.4	81.5
Coarse Agg., kg	120.4	120.4	120.4
Water-Cement Ratio	0.60	0.50	0.40
Water Reducing Agent, Ml	50.5	64.4	80.9
Air Entraining Agent, Ml	0.1	0.3	0.5
Designed Slump, mm	90	90	90
Designed Entrained Air, %	6 ± 1	6 ± 1	6 ± 1

After the samples were poured, they were cured at room temperature for 14 days in the moisture room, then for 14 days in the laboratory at room temperature ($21^{o}C$), to give a total of 28 days curing time.

After curing, the samples were immersed in 4% sodium chloride (salt) solutions. Three stainless steel tanks were used, one for each metal series. The samples

were immersed to a depth of 200 mm, leaving the upper third of the concrete above the level of the brine. Figure 1 shows the test tanks. In each of these tanks, concrete prisms of each strength of concrete were placed so that cores could be taken at a series of times to determine chloride penetration. These prisms measured 150 mm x 145 mm x 300 mm high.

At the beginning of the test, and once a week thereafter, copper-copper sulphate half cell potential readings were taken by pressing a salt bridge (copper sulphate saturated solution in a flexible tube) against the sample, over the rebar and just above the solution level. At each reading, the samples were examined to see if any cracks had developed.

At the end of three years' immersion, no cracks had developed, but rust stains had developed on two of the samples. These were black iron rebars, 17.2 MPa cement with 18 mm cover. None of the other samples showed any distress.

The potential of the specimens and their change with time, is shown in Figures 2, 3, 4, 5, 6, and 7.

Figure 2 shows the curves for low strength concrete (17.2 MPa) with three depths of cover. In less than eight days, the salt had penetrated to the rebar in the low cover sample and, as the salt concentration increased, the potential began to rise, and corrosion began. This was determined by the potential reaching -350 mV. It took longer, about 75 days, before the medium cover sample began to corrode. The potentials continued to rise and levelled out at around -650 mV for the low and medium cover, and -500 mV for the high cover samples.

Figure 3 shows the potential curves for the black iron medium strength - (27.6 MPa) samples. Here, there was a longer period of time before the onset of corrosion. All three covers of concrete started out at -120 mV and began to rise, except the high cover, which held this potential for three months.

In the case of the low cover concrete, corrosion did not begin for 145 days, the medium cover sample 275 days, and the high cover sample 1,120 days. The potentials all continued to rise after these points, as shown in Figure 3.

Figure 4 shows the potential curves for the high strength (3 .5 MPa) black iron samples. Here, the potentials remained at -120 mV for a longer time and did not begin to change until the salt penetrated to the rebar. In the case of the low cover, the potential held at -120 mV for 3 months, then started to rise and, after 270 days, reached the corrosion potential of -350 mV and continued to rise and levelled out at -500 mV. In the case of the medium cover, the potential held at -120 mV for 11 months and reached the corrosion potential only after 100 days and continued to rise. In the case of the high cover, the potential held reasonably constant at -120 mV for the whole three years, showing that the salt did not reach the rebars in that length of time.

The situation was different where the galvanized rebars were concerned. Figure 5 shows the potential curves for the low strength bars (17.2 MPa) in three covers of concrete. All three show a rapid rise in potential within one week after the samples were immersed in the bath, indicating that the salt solution had penetrated to the rebars and the zinc was corroding. As the zinc reacted, a passivating film built up and the reaction slowed down, as shown by the drop in potential. Then, as more chloride migrated to the bar and its concentration increased, the corrosion attack began again with increased vigour, as shown by a sudden rise in potential. This is in accord with the findings of Unz (17). The zinc passivates at low chloride concentrations, then at high concentrations inherent currents develop, and severe attack begins on previously passivated surfaces.

The same effect can be seen in Figures 6 and 7 for the medium and heavy strength concretes. As the concrete strength and cover increased, there was a lower and lower potential on the rebars, showing a decreased amount of attack. In the medium and heavy cover, high strength samples in Figure 7, there was no attack visible. Here, the chloride had not penetrated to the rebar. The samples in the third bath - those containinng chromated rebars - behaved the same as the galvanized only rebars. The results are, therefore, not reported here.

These results indicated that the zinc was being attacked where there was a continuous supply of chloride, as in these immersed samples. Eventually, fracture of the concrete should occur. At the end of the three years reported above, no fractures had occurred. It was then decided to make a different arrangement of the samples and intersperse the galvanized and black iron rebar samples. The idea was to place the galvanized samples between black iron samples which were corroding, to see if the galvanized samples would corrode faster in a sacrificial mode to protect the iron. There were, however, no connections made between the rebars. These samples were examined weekly and their potentials measured against the copper-copper sulphate half-cell. For one year, this process was continued and no change occurred in the potentials of either the galvanized or iron samples. Thus, at the end of four years, none of the samples showed any sign of cracks or distress, with the exceptions noted above, of some iron rust coming through the pores of some low cover, low strength black iron samples.

It was then decided to couple twelve sets of galvanized and black iron samples together to force the galvanized samples to protect the black iron samples.

Core samples had been taken periodically from the concrete prisms stored in each bath and the chloride penetration into the cement determined. After four years, the chloride seemed to be approaching the rebars of the high strength, high cover samples. It was then decided to couple galvanized rebar samples to black iron samples where some of the latter were already corroding. Wires were soldered between the rebars to couple them electrically. One plain galvanized and one chromated galvanized sample were connected to each chosen black iron sample and the twelve sets of coupled samples continued to be immersed in the 4% salt baths. The arrangement of coupled samples is shown in Table I. In this table, only the plain galvanized bar sample and black iron sample are shown. The chromated sample had the same properties as the plain galvanized sample.

The potentials of each sample were measured before coupling, then once a week after coupling. Figure 8 shows how the potentials varied for one of the couples. Immediately after coupling, the potential of the zinc sample dropped

and evened out with that of the black iron sample, then rose again to a level value. The potential of each of the three samples in a couple remained the same, then proceeded to drop slowly over a long period of time. At the end of 400 days, no cracks had developed in any of the samples. It was then decided to take one galvanized sample off each couple so that the sacrificial action would be concentrated in one sample alone. To do this, all of the chromated samples were removed and the observations continued. After approximately 560 days, cracks were noticed in six of the galvanized samples, the remaining six remaining in good condition. After the cracks developed, the potential of the specimens showed a slow rise. One couple showed a very rapid rise after the chromated sample was removed and kept the high potential until it also cracked. These values for all couples are shown in Table I. These samples are still immersed in the bath, and observations will continue. The galvanic current flowing in each sample is also shown in Table I. These were measured by a Zero Resistance Ammeter, and are much higher for the samples which cracked.

The rate of penetration of salt into the concrete can be seen in Figures 2, 3, and 4. When the salt reached the rebars, the potential began to rise slowly and continued to rise, passing the -350 mV value which, according to Stratfull (3), is considered the corrosion potential. The time to corrosion for each of the three strengths of concrete and different depths of cover are shown in Figure 9.

The salt profile in each of the three strengths of concrete after 5½ years' immersion, is shown in Figure 10. These figures show that the high strength concrete, 34.5 MPa (5000 psi) is much more resistant to salt penetration than the low strength concrete.

The coupled samples, where the zinc is corroding to protect the iron, show that fracture can occur over galvanized rebars under these circumstances. To date, no uncoupled galvanized samples have cracked after 5½ years. The potentials of these samples do show, however, that the zinc is corroding and eventually, cracking most probably will occur. This will occur when there is a plentiful supply of chloride in the concrete.

Instrumented Galvo Bridge Deck

In 1976, Metro Toronto was replacing the Bathurst Street bridge, which is situated over a ravine north of St. Clair Avenue, with a new structure. All of the reinforcing steel in the slab deck of the new structure was galvanized by the hot dip process. Permission was obtained from Metro Toronto to install probes in the deck to monitor the corrosion rate of the zinc coating. The probes were three element polarization probes and resistance probes made from high purity zinc.

The polarization probes were symmetrical three element probes for determining corrosion rate by the linear polarization technique (19). These were calibrated using a "Petrolite M 212" meter and comparing the reading to that obtained with calibrated Petrolite pure zinc electrodes. Two of these probes were positioned in the bridge, as shown in Figures 11 and 12, under the sidewalk and under the paved deck. The probes were fastened to the upper level of the rebars and the working electrode of each probe was connected electrically to the galvo rebars. Each probe was thus an integral part, electrically, of the structure.

The resistance probes were made from specially rolled, 10 mil high purity zinc. These probes represent two arms of a Wheatstone Bridge, a protected arm and an exposed arm. The exposed arm was connected electrically to the galvo rebars. These probes were read by a "Corrosimeter" meter so that the change in resistance of the exposed arm would be determined. A large change with time would show rapid corrosion, and a small change reduced corrosion rate. The resistance probe locations are shown in Figures 11 and 12. The leads from all these probes were brought to a box mounted on the soffit of the bridge for easy access.

Readings were taken before the cement deck was poured and frequently for some time after pouring then, twice a year in spring and fall. The results are shown in Figures 13 and 14.

The polarization probe results shown in Figure 13, show a high corrosion rate initially, due to the high pH of the concrete. This rate decreased with time, showing a passivating effect - possibly due to the formation of a zinc compound plating out on the bar. Now, five years later, the rate is very small, showing that the zinc has almost passivated. There is, however, a consistent variation between the spring and fall readings. If a large amount of chloride ion migrates down through the concrete, this passivation could be destroyed and corrosion begin anew, as was shown in the laboratory samples. This deck has been paved and one probe, No. 1 in Figure 12, is under the pavement, while the other is under the sidewalk.

A similar effect is shown in Figure 14 for the resistance probes. Here, the corrosion rate was quite visible at the beginning on three of the four probes. This rate slowed down and almost stopped after two-and-one-half years.

Both the polarization and resistance probes show that the zinc rebars had been polarized and the corrosion has been virtually stopped. At the beginning, after the concrete was first poured, the corrosion rate was high. This was due to the high pH of the concrete. What is not known at present, is: has the deicing salt penetrated to the rebars, and has it had any effect on the corrosion. At present, the rebars are in an almost passive condition and not corroding due to the passivating film formed on the bars. It would be most interesting to know at the present, if the salt has penetrated to rebar level. This could easily be determined by taking core samples from the concrete sidewalk and analyzing the sliced core samples.

County Bridge, Wingham

In 1975, a post-tensioned deck was built in Wingham using galvanized rebars. Copper-copper sulphate half cell surveys were taken on this deck from 1975 to 1980, to determine the potential of the galvanized rebars. The potentials across the deck varied as follows:

Year	Potential, m V
Nov. 1975	- 900 to - 1,170
1976	- 500 to - 640
1977	- 640 to - 780
1980	- 200 to - 350

In 1976, a 50 mm core was removed from the deck and the core contained a section of rebar. This sample had a potential to copper-copper sulphate of - 600 mV. The core was placed in the moisture room over the weekend and, when measured the following week, had a potential of 1,000 mV. In 1980, another core was taken, and it had a low potential of about - 300 mV. This was placed in the moisture room and its potential only rose to - 400 mV.

The rebars in this deck are also in a passive condition at present. What will happen in the future after more salt penetrates the deck, is unknown. If a sufficiently high salt and moisture condition can be brought about, it is possible that the passivating film may break down and corrosion start again.

CONCLUSIONS AND RECOMMENDATIONS

It is difficult at the present stage of this investigation to make any definite conclusions regarding the use of galvanized rebars. It is obvious that zinc corrodes under the high pH of concrete, and then passivate due to the formation of a film of corrosion products.

Conclusions and Recommendations - (cont'd.) . . .

If a continuous supply of moisture and salt are present, this passivating film breaks down and corrosion begins anew which could cause damage to the concrete. This recurrence of corrosion has been shown to happen in the laboratory under conditions where the samples are kept partially immersed in a salt solution.

It is not possible, at present, to relate these laboratory results to an exposed bridge deck. In the case of a deck, it receives salt only in winter time, and there are alternate wetting and drying cycles throughout the year. At present, we do not know if salt has penetrated to the rebars of either of the bridge decks under observation.

It is recommended that:

1. The coupled samples in the laboratory be kept under observation for corrosion current, potential and crack formation.

2. Cores be taken from both bridges and the salt profile in the concrete be determined.

3. Copper-copper sulphate half cell surveys be continued on the County bridge and be initiated on the Metro Toronto bridge. This latter will require a normal survey on the sidewalk, but 1/4" holes will have to be drilled through the asphalt surfacing in a few places to get readings on the asphalt covered deck.

4. Readings continue to be taken twice yearly on the polarization and resistance probes on the Metro Toronto bridge.

5. The above observations - 2, 3, and 4 - be continued for several years to determine how the rebars will react with time and increasing salt concentrations.

REFERENCES

1. NCHRP Synthesis 4, "Concrete Bridge Deck Durability" (1970).

2. NCHRP Synthesis 57, "Durability of Concrete Bridge Decks" (1979).

3. Spellman, D.L. and Stratfull, R.F., "Chlorides and Bridge Deck Deterioration" Highway Res. Rec. 328, p 38 (1970).

4. Crumpton, C.F., "Corrosion and Kansas Bridges" Transp. Res. Record 500, p 25 (1974).

5. Fromm, H. J. and Wilson, G.P., "Cathodic Protection of Bridge Decks, A Study of Three Ontario Bridges" Transp. Res. Rec. 604, p 38 (1976).

6. Shalon, R. and Raphael, M., "Influence of Seawater on Corrosion of Reinforcement" Proc. Am. Concrete Inst. 55 No. 12, p 1251 (1959).

7. Clear, K.C., "Time to Corrosion of Reinforcing Steel in Concrete Slabs" Transp. Res. Rec. 500, p 16 (1974).

8. Weed, R.M., "Recommended Depth of Cover for Bridge Deck Steel" Transp. Res. Rec. 500, p 32 (1974).

9. Lewis, D.A., "Some Aspects of the Corrosion of Steel in Concrete" Proc. of the First Int. Cong. on Metallic Corrosion. London, 1962, p 547.

10. Pike, R.G., et al. "Nonmetallic Protective Coatings for Concrete Reinforcing Steel" Transp. Res. Rec. 500, p 36 (1974).

11. Clear, K.C., FCP Annual Progress Report, Year Ending Sept. 30, Project 4K, Federal Highway Administration (1980).

12. Baker, E.A., Money, K.L., and Sanborn, C.B., "Marine Corrosion Behavior of Bare and Metallic Coated Steel Reinforcing Rods in Concrete" ASTM - STP 629 (1977).

REFERENCES - (cont'd.) . . .

13. Stark, D. and Perenchio, W., "The Performance of Galvanized Reinforcement in Concrete Bridge Decks" Portland Cement Assoc. Final Report, Project ZE-206 (1975).

14. Cornet, I. and Bresler, B., "Corrosion of Steel and Galvanized Steel in Concrete" Materials Protection, April 1966, p 69 - 72.

15. Ishikawa, T., Cornet, I., and Bresler, B., "Electrochemical Study of the Corrosion Behavior of Galvanized Steel in Concrete" Proceedings of the Fourth International Congress of Metallic Corrosion (Sept. 1969).

16. Arup, H., "Galvanized Steel in Concrete" Materials Performance, April 1979, p 41.

17. Unz, M., "Performance of Galvanized Reinforcement in Calcium Hydroxide Solution" ACI Journal, Mar. 1978, p 91.

18. Hill, G.A., Spellman, D.L., and Stratfull, R.F., "Laboratory Corrosion Tests of Galvanized Steel in Concrete" Transp. Res. Rec. 604, p 25 (1976).

19. Dean, Jr., S.W., "Electrochemical Methods of Corrosion Testing" Symposium "Electrochemical Techniques for Corrosion" Ed. R. Baboian N.A.C.E., Houston, Texas.

TABLE 1

GALVO - BLACK IRON SAMPLE COUPLES

Sample Couple*						
No.	Plain Galvo Bar M Pa	Black Iron Bar M Pa	Time to Fracture Days	Fracture	Potential at Fracture	Corrosion Current μA
1	LC 17.2	LC 17.2	-	No	-	+ 56
2	MC 17.2	MC 17.2	-	No	-	+ 26.5
3	LC 27.6	LC 27.6	-	No	-	+ 27
4	MC 27.6	MC 27.6	-	No	-	- 9.5
5	LC 34.5	LC 34.5	-	No	-	+ 17
6	MC 34.5	MC 34.5	470	Yes	- 600	+350
7	LC 17.2	HC 34.5	470	Yes	- 650	+175
8	MC 17.2	HC 34.5	470	Yes	- 600	+132
9	LC 27.6	HC 34.5	470	Yes	- 500	+225
10	MC 27.6	HC 34.5	470	Yes	- 575	+135
11	LC 34.5	HC 34.5	470	Yes	- 900	+ 84
12	MC 34.5	HC 34.5	-	No	-	+ 42.5

Couple*

LC = 18.5 mm cover, MC = 38 mm cover.

HC = 63 mm cover.

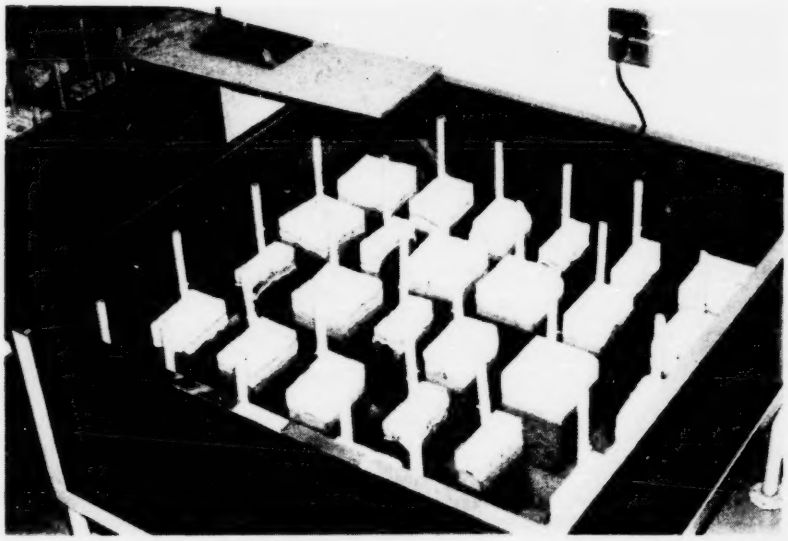


FIGURE 1

Galvo Rebar samples in 4% salt solution.
Three different depths of cover showing.

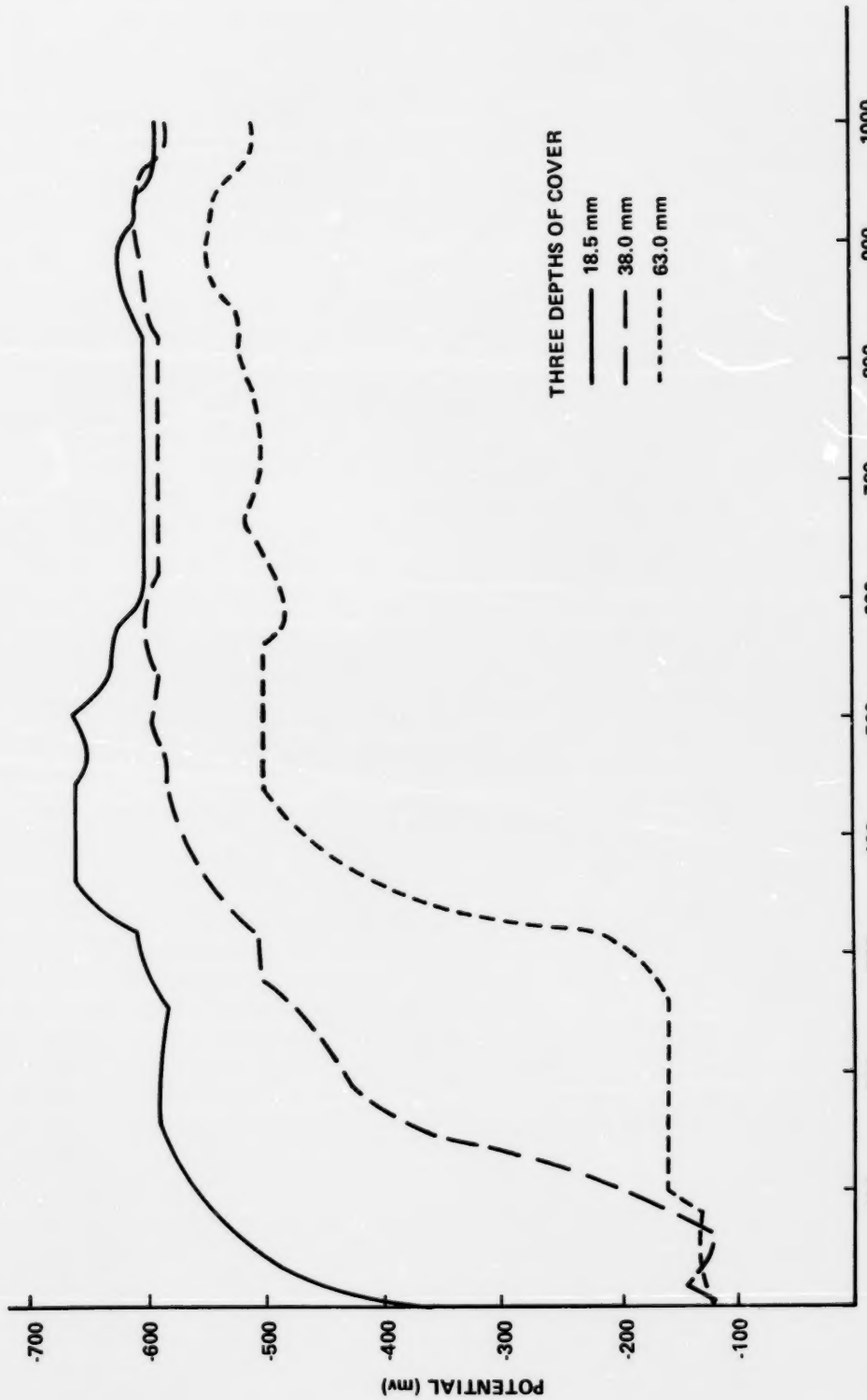


Figure 2/ Black Iron Rebar Samples, 17.2 MPa Concrete in 4% Salt Solution

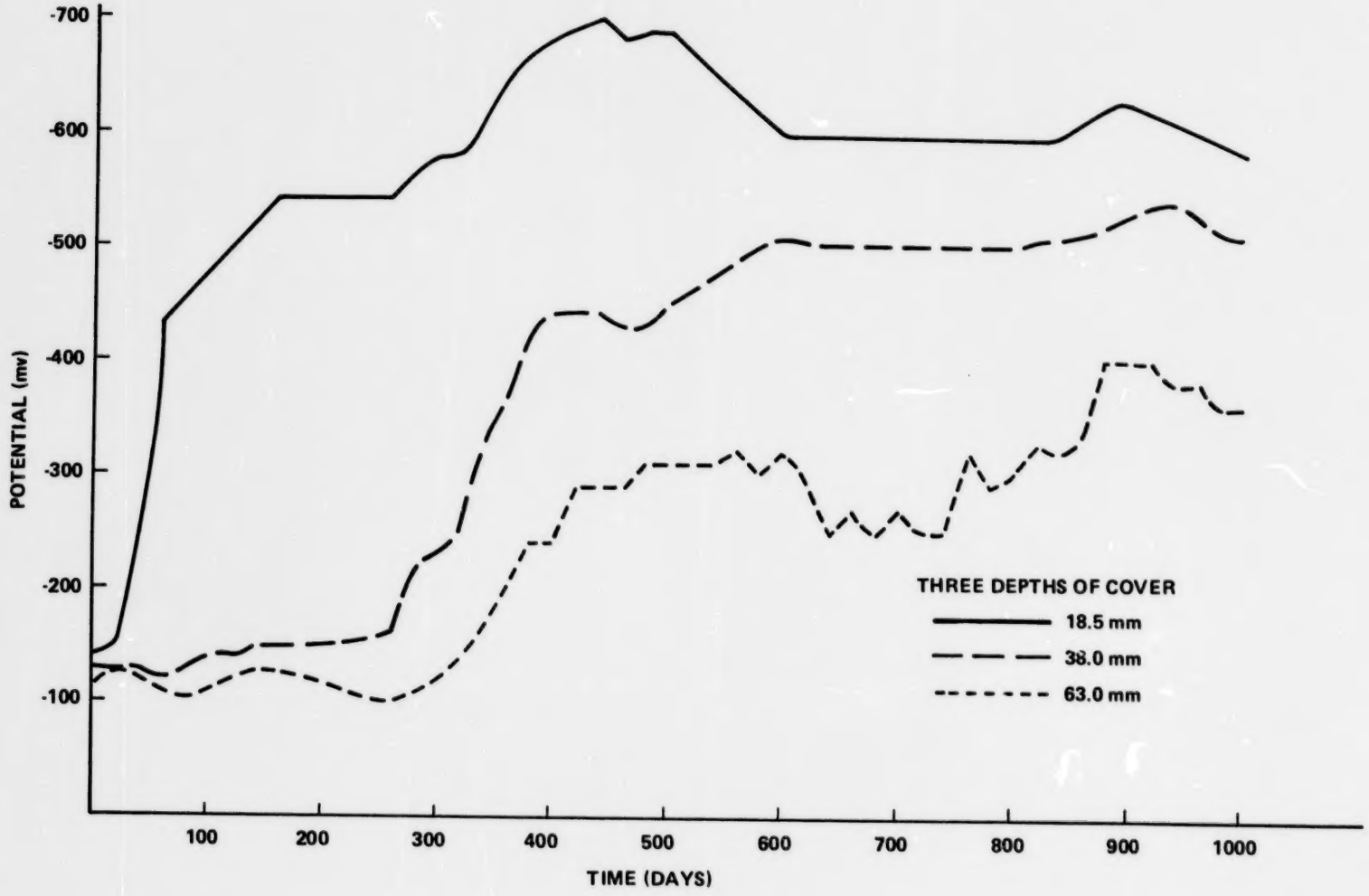


Figure 3/ Black Iron Rebar Samples, 27.6 MPa Concrete in 4% Salt Solution

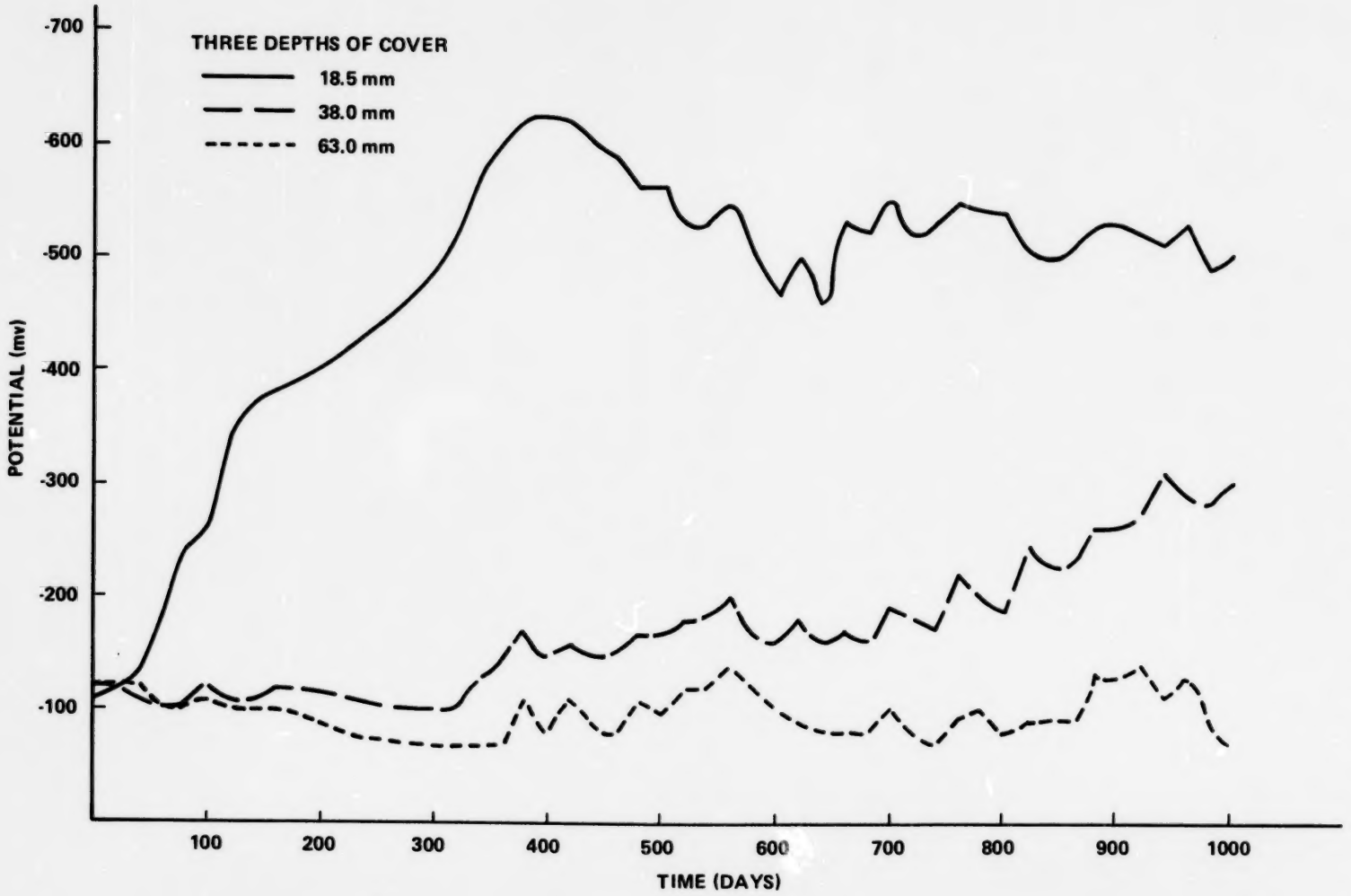


Figure 4/ Black Iron Rebar Samples, 34.5 MPa Concrete in 4% Salt Solution

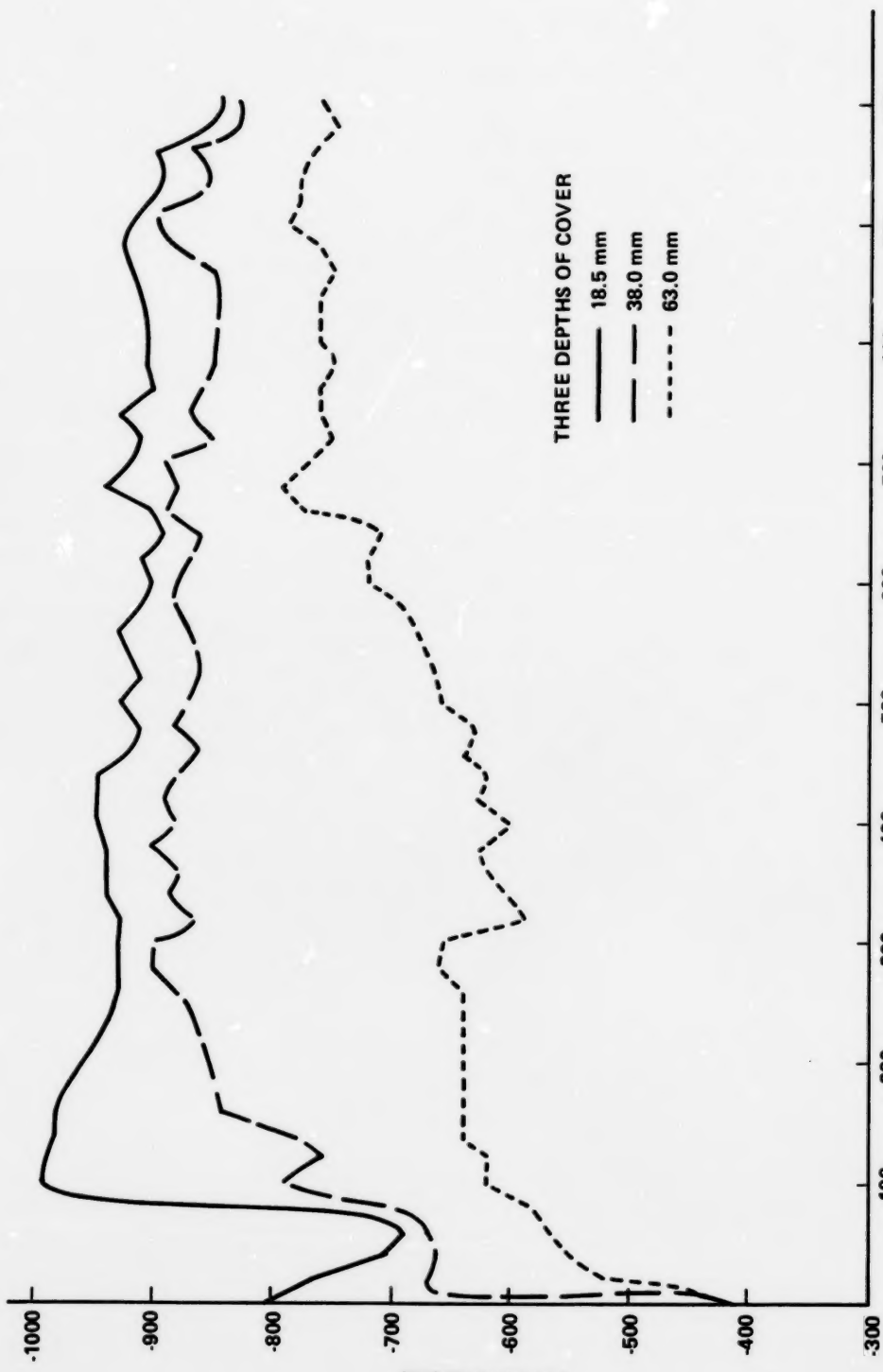


Figure 5/ Galvanized Rebar Samples, 17.2 MPa Concrete in 4% Salt Solution

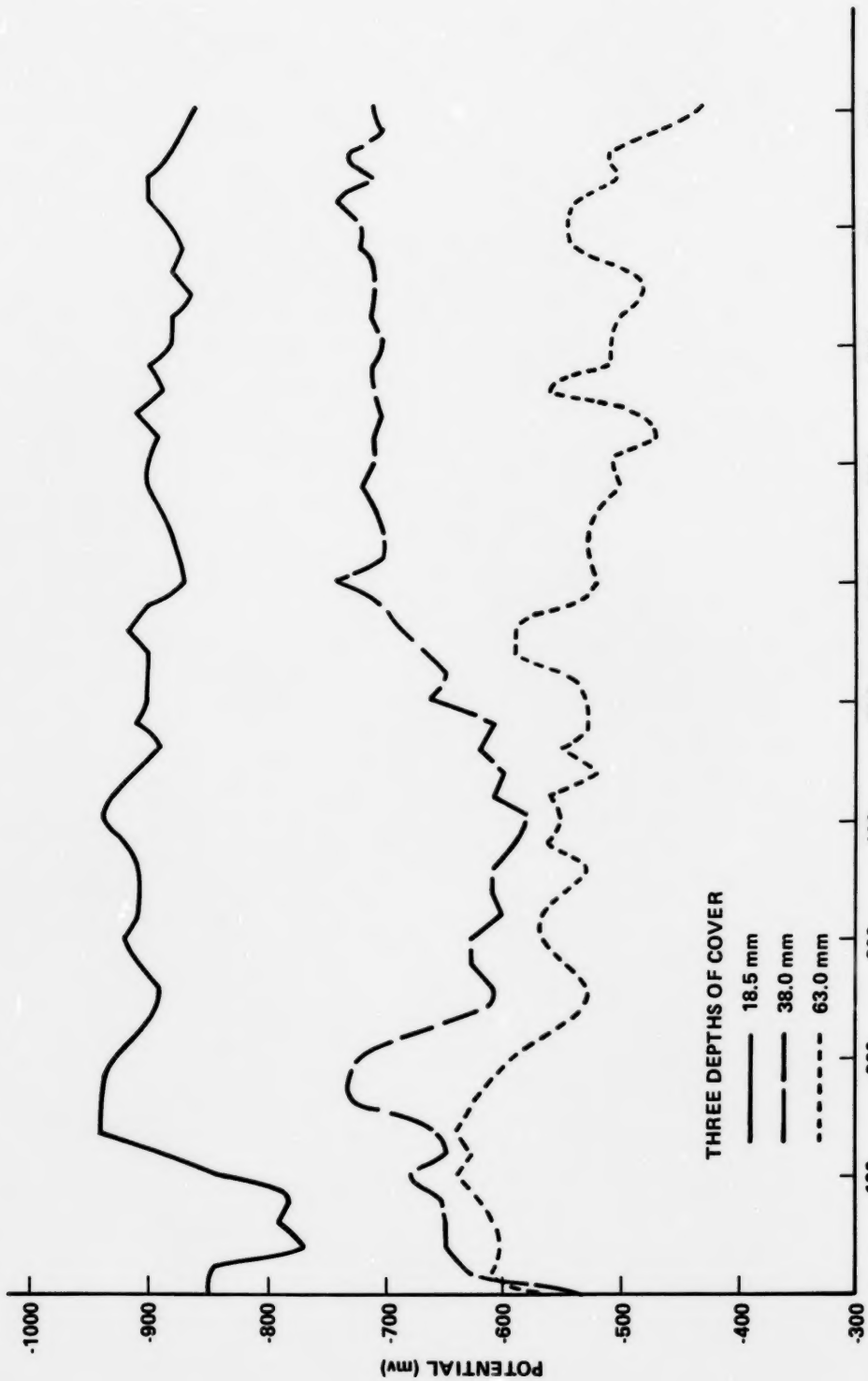


Figure 6/ Galvanized Rebar Samples, 27.6 MPa Concrete in 4% Salt Solution

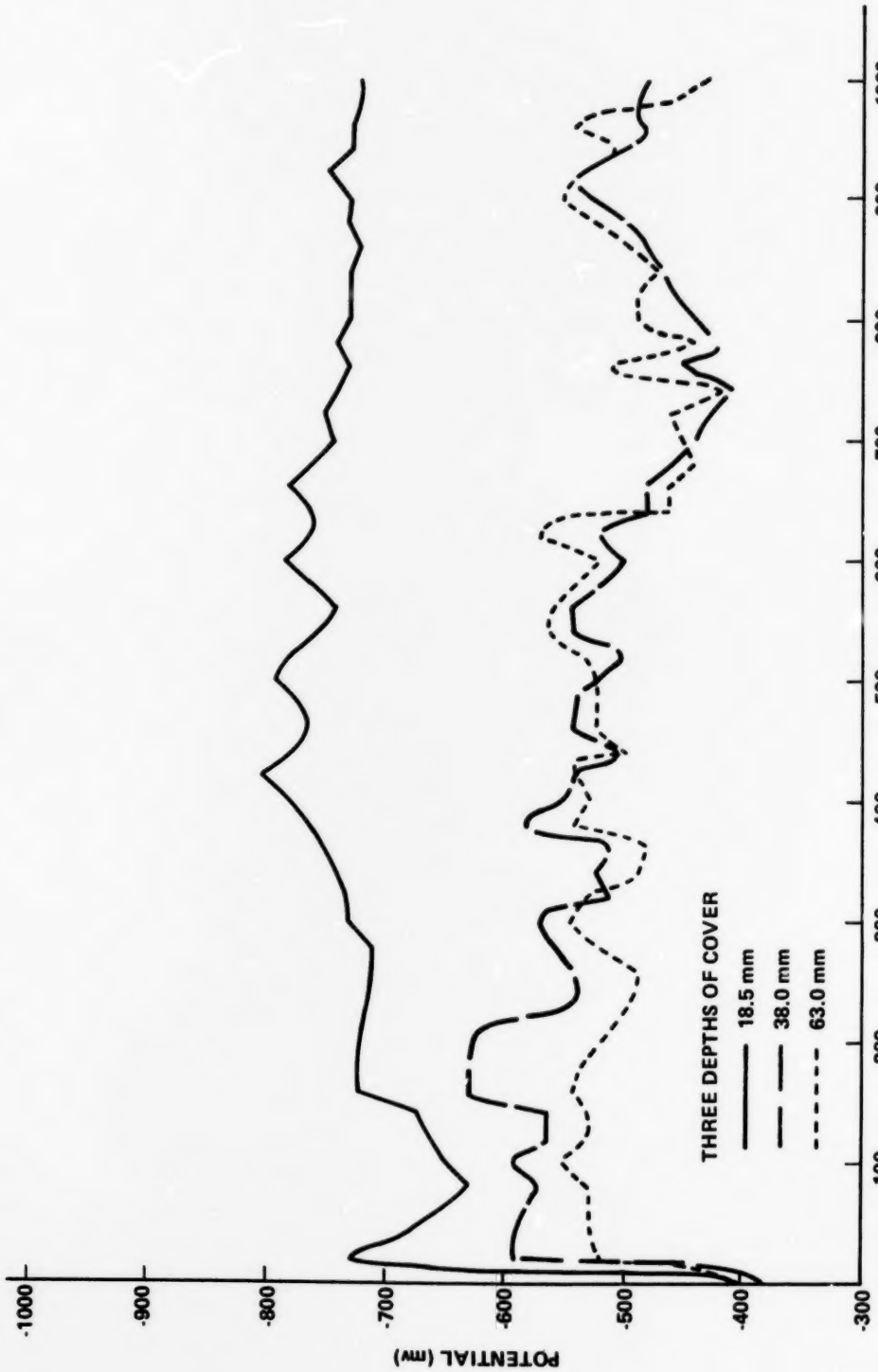


Figure 7/ Galvanized Rebar Samples, 34.5 MPa Concrete in 4% Salt Solution

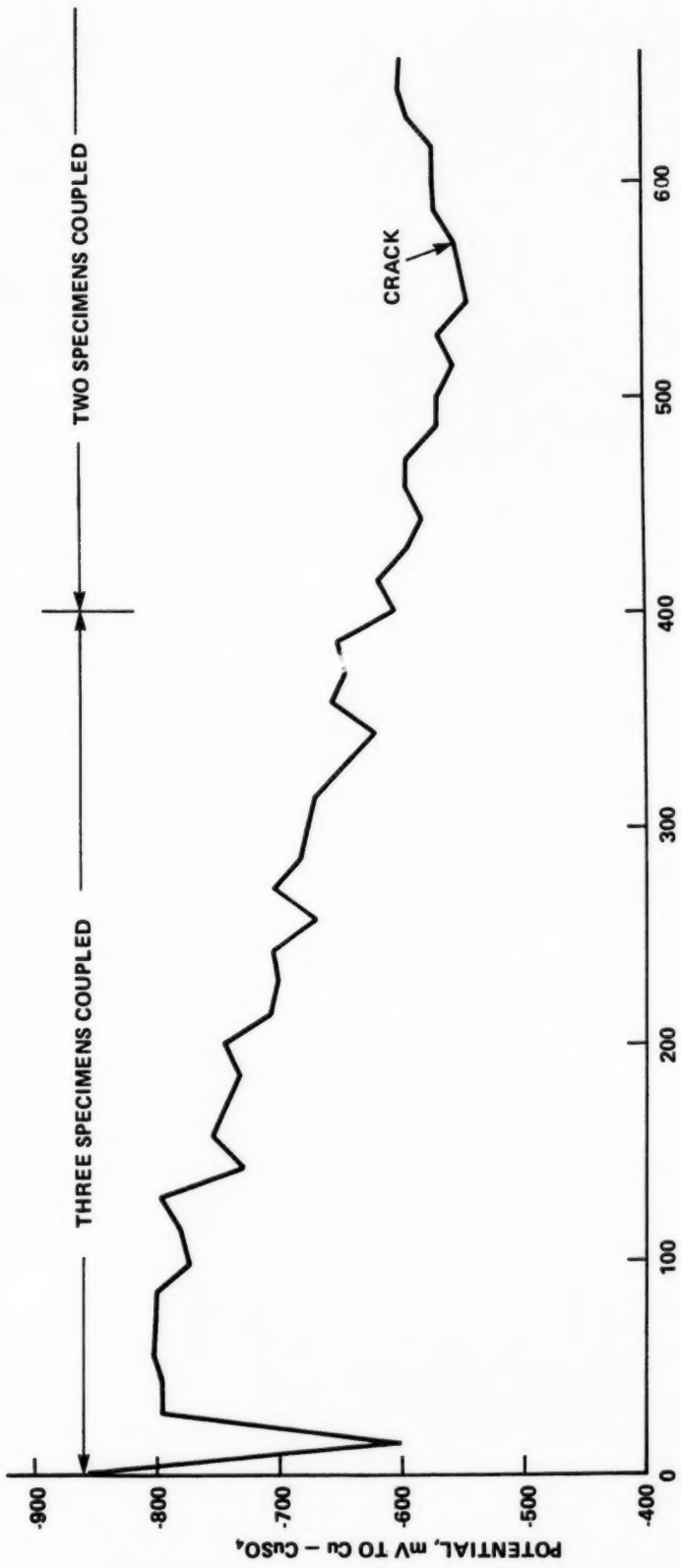


Figure 8/ Potential to Cracking of Galvo-Black Iron Sample Couple in 4% Salt Solution

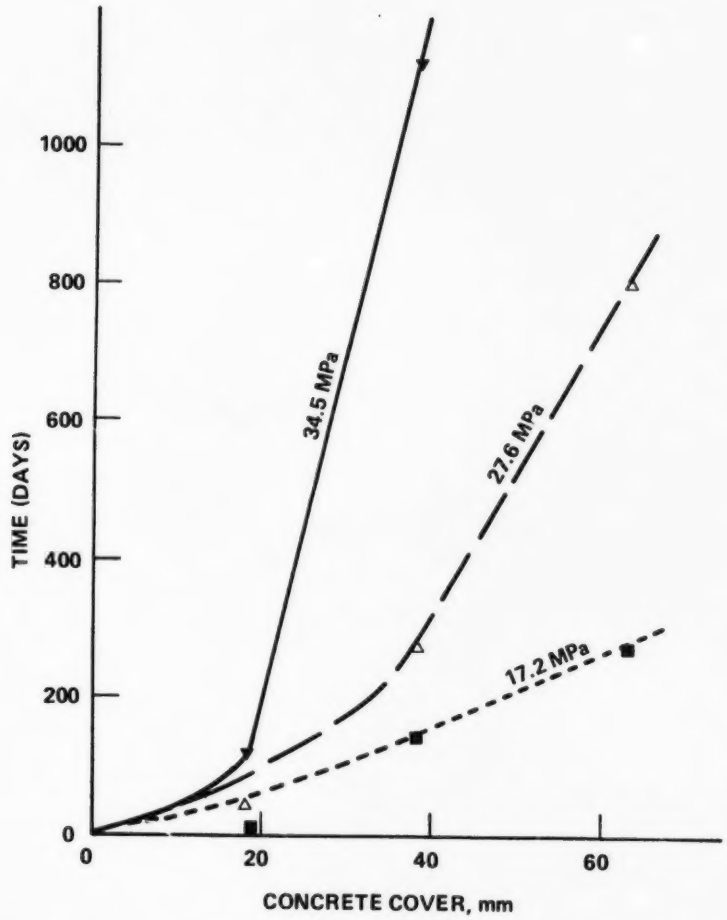


Figure 9/ Black Iron Rebars, Time to Corrosion (−350 mV) vs Depth of Cover for Different Concrete Strengths

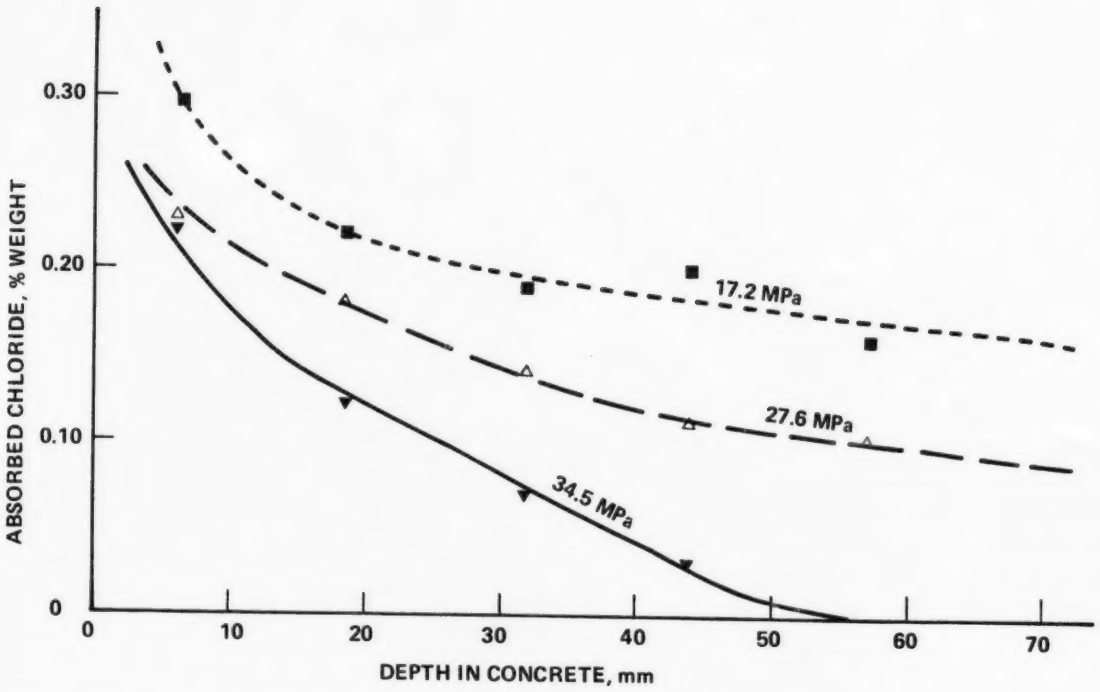
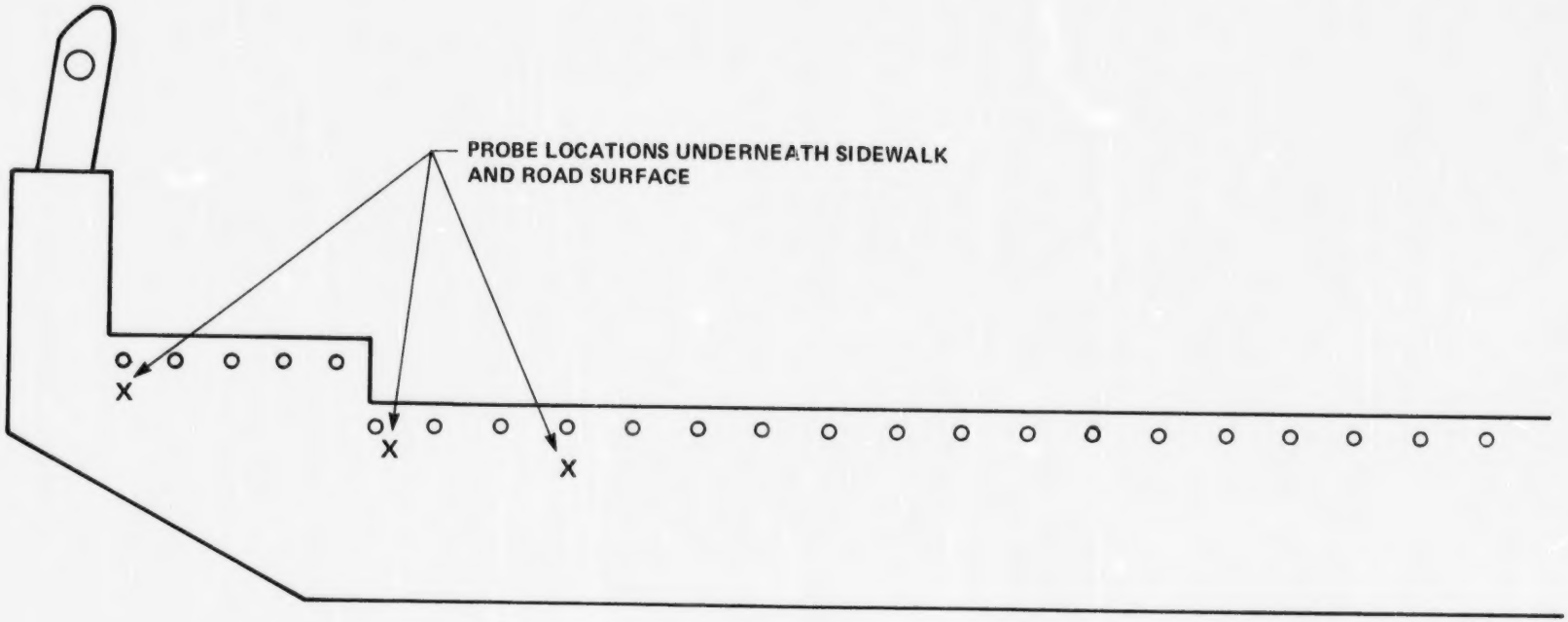


Figure 10/ Salt Pentration into Concrete, mm, After 5½ Years Immersion



PROFILE VIEW

Figure 11/ Metro Toronto Bridge Probe Location

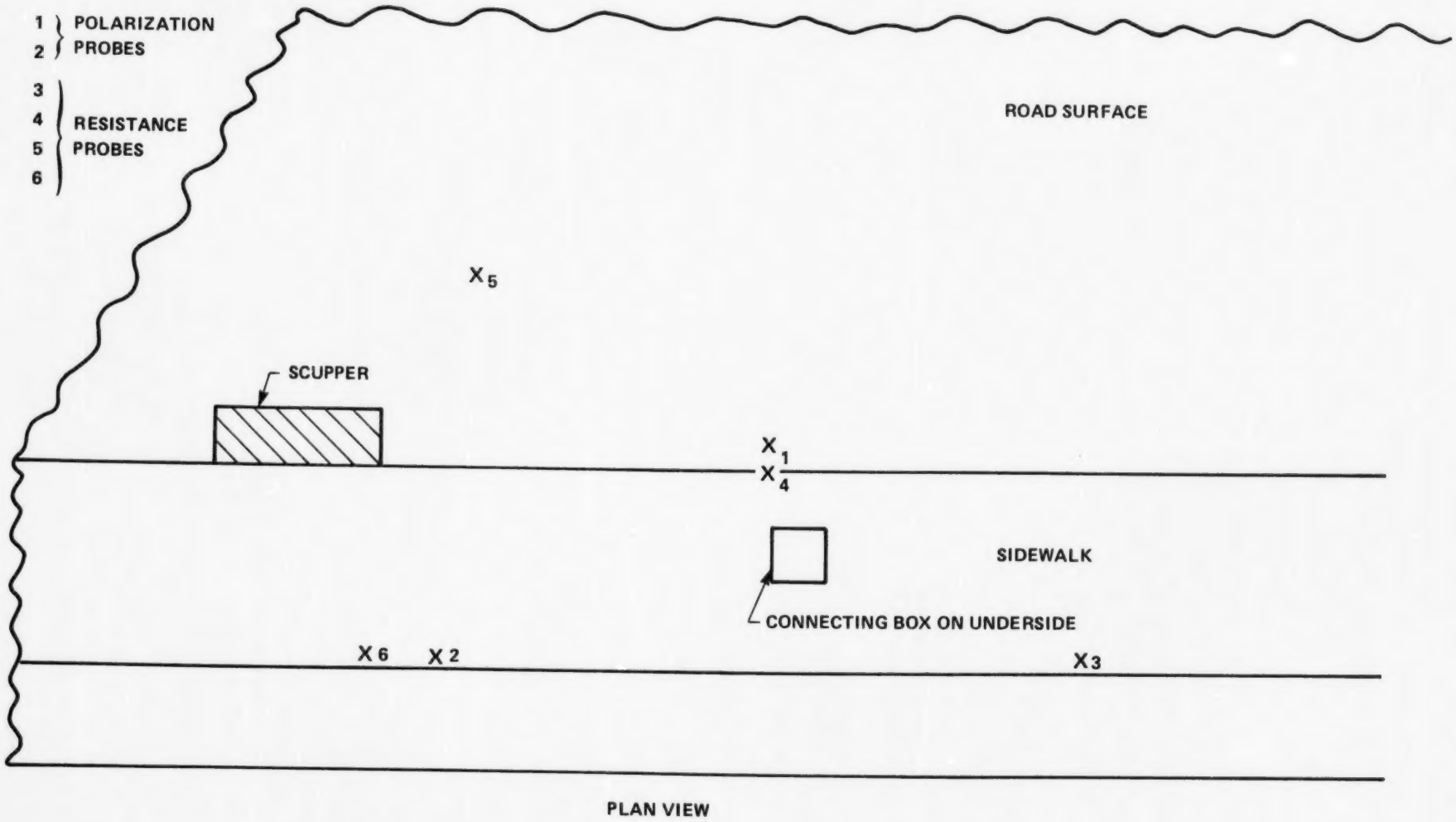


Figure 12/ Metro Toronto Bridge, Probe Location

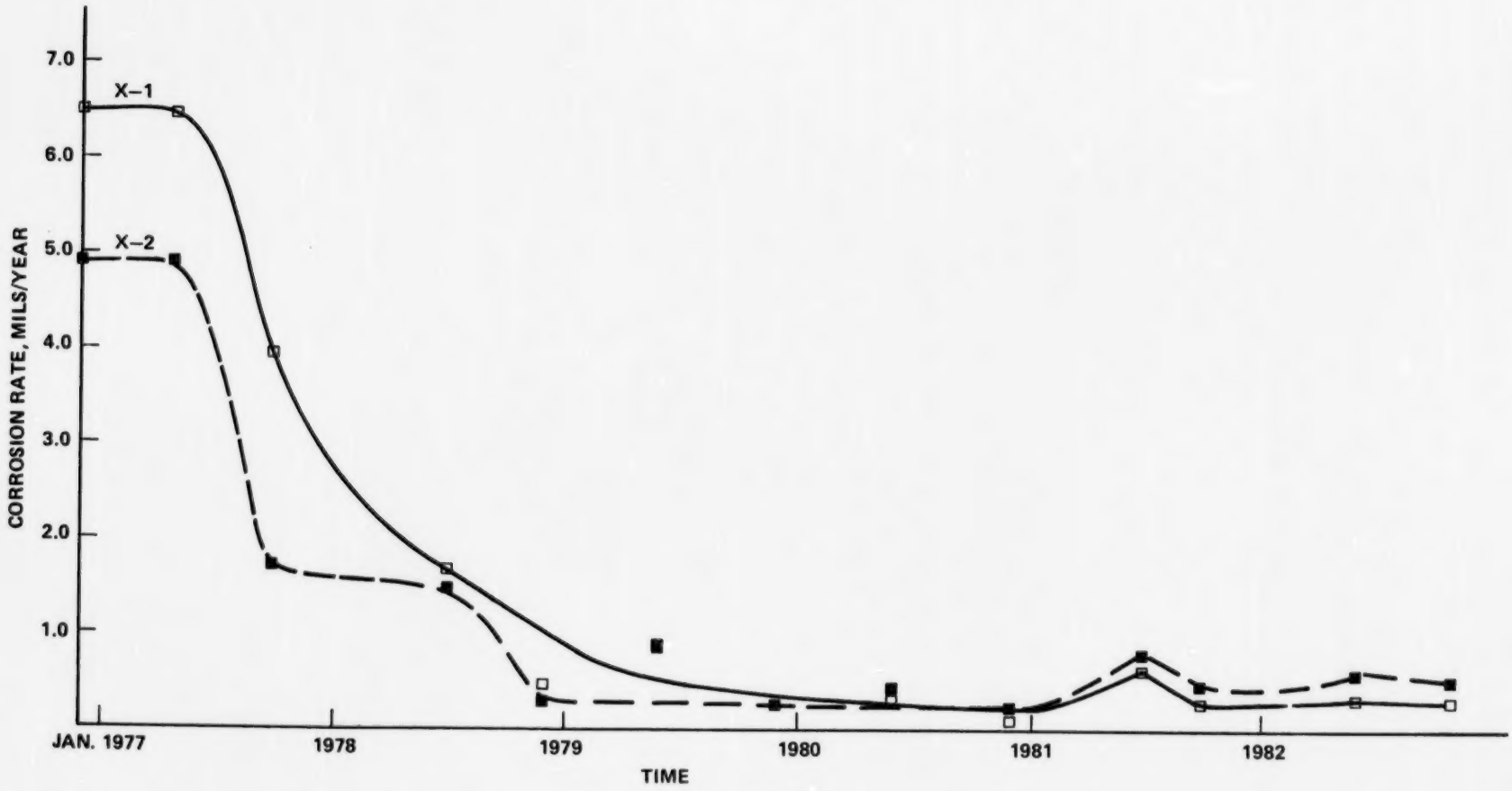


Figure 13/ Metro Toronto Bridge, Rate of Galvo Rebar Corrosion

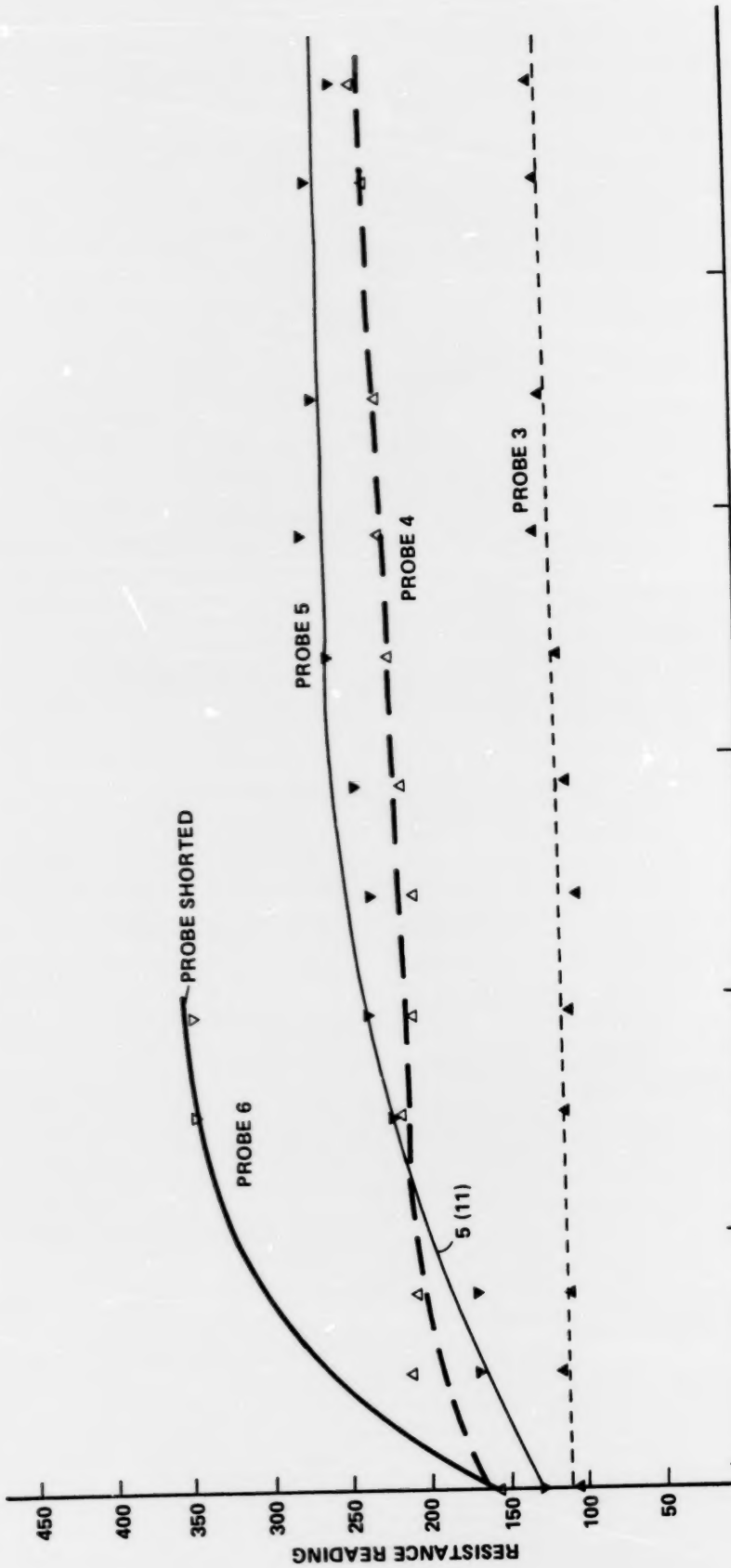


Figure 14/ Resistance Probe Readings, Metro Toronto Bridge